Research on Reservoir Damage Mechanism and Protection Technology of Fracture- void Dual Medium Reservoir

Liu Zhong-yun[1,2] Hu Xiao-dong[2] Xiong Yu-juan[2] Yang Xue[2] Liu Shuang[2]
1 Chongqing Energy College, ChongQing，China
2 Petroleum Engineering College, Yangtze University, Jinzhou, China
Liuzhongyun2006@163.com

Abstract: **The reservoir harm mechanism and protection technology of fracture-void dual medium reservoir in the drilling process were reviewed. The reservoir mechanisms included solid phase invasion, reservoir fluid sensitivity, stress sensitivity, water-lock effect and so on. Selecting appropriate drilling fluid system and using necessary drilling craft including shielded temporary plugging technology (crack width < 100μm) and underbalanced drilling technology (crack width >100μm)) were the reservoir protection methods of dual medium reservoir. Determination fracture effective flowing width accurately and selecting optimally temporary plugging agent matching up with the reservoir were the key of shielded temporary plugging technology. Selecting reasonable wellbore fluid and appropriate negative pressure was the core of underbalanced drilling technology. It is pointed that superiority supplementary of underbalanced drilling technology and shielded temporary plugging technology is the development direction of fracture-void dual medium reservoir protection in the future.**

Keywords: dual medium reservoir; reservoir harm; reservoir protection; shielded temporary plugging technology; underbalanced drilling technology

Nowadays, fractured reservoir and affected fractured reservoir are increasing each year in oil-gas reservoir. Both their reserves and output increase in proportion[1～3]. Based on the incomplete statistics, the oil-gas reserves of complex fractured reservoir take up about 50% of the total reserves [4]. The best economic effectiveness oil deposit is the fractured reservoir [5], because this kind of reservoir provides good seepage channel which connected to the shaft. However, the research also shows [6] that some fractured reservoirs had been drilled but without expected high production. This is because in the process of drilling, oil layer is contaminated by working fluid so that the fracture is deeply blocked and the flow resistance is increased. Therefore, protection technology of fracture-void dual medium reservoir arouses people's attention. Because of the research and practice done in previous years, the protection technology of fracture reservoir is relatively mature[7～9], but protection technology of fracture-void dual medium reservoir has not been mature yet. This paper based upon the references both at home and abroad analyzes reservoir damage mechanism and protection technology of fracture-void dual medium reservoir in order to provide some methods on dual medium reservoir.

I. RESERVOIR DAMAGE MECHANISM OF FRACTURE-VOID DUAL MEDIUM RESERVOIR

A. *Solid Phase Invasion*

Solid phase blocking exists in every chain of operations in reservoir seepage channel (well drilling, well completion, well repair, increase in production, water injection). During the process of well drilling, there are two kinds of circumstance [11]:① The outside solid phase particles (harmful solid phase particles and cement particles) which are less than the effective width of the crack invade deeply into the crack of the stratum or are absorbed by the crack surface to form membranes, which causes the reduction of seepage capability of the crack. The damage depends on the depth of invasion, the size of solid phase particles, formation of filter cake and differential pressure; ② The particles' migration of dual

medium reservoir cause damage to reservoir. Because the exogenic action leads to the particles migration of the gouge, secondary mineral and diagenetic mineral (quartz and bed rock mineral) existed in the crack, it forms precipitation and block crack, and influences the seepage channel, to reduce the transfusion of the reservoir; ③ In the process of well drilling exploration, leakage, the dual medium stratum (barranca or low pressure and low permeability), is the most important factor caused damage to the reservoi. Because of existence of differential pressure and reservoir crack, harmful solid particles (clay, weighting material, drilling cuttings) in drilling fluid could transit along with the stretch of crack, go further into the deep crack and hard to return, also increase the seepage resistance of reservoir fluid flowing to shaft and cause serious damage to production. Usually which is located around the shaft within the radius of 1-1.5m contributes to the reduction of reservoir permeability and without production fluid or low production fluid after operations or perforations. It will cause severe damage if the particles whose diameter is less than 100μm enter into reservoir and affect the extensively developed micro fractures; it brings invasion of abundant solid particles and blocks wider cracks. Under the circumstance of reservoir pressure, to the reservoir whose width is more than 100μm the biggest problem faced in the well drilling construction is the loss of reservoir. The reason may have following types[12]:(1)loss under the positive pressure; (2)gravity loss; (3)replacement loss; (4)cavern porosity formation; (5)other losses (namely loss, simultaneous lost circulation and blowout, underground blowout). The most serious stratum damage of the loss could be solid-phase damage. Because 90% of grain size of the solid particles is less than 50μm so that when the crack diameter is more than 50μm almost all the solid phase can enter into the crack to cause serious blocking.

B. Reservoir Fluid Sensitivity

Since early 60s of 20 century, most of Chinese oil and gas geology laboratories have established five sensitivity (water sensitivity, acid sensitivity, alkali sensitivity, salt sensitivity and velocity sensitivity) test methods. Testing results are used to restrain clay swelling, to reasonably apply acidification using fluid, to adjust water salinity and to correctly control production flow velocity[13～17]. Wang Xin and others discuss the effects on particle caused by gravity, van der waals force, electric double layer, and hydrodynamic force and stress on the influencing factors of particles hydration scattered, the migration of critical concentration, and critical startup speed [18] ,based on the force analysis of particles. Kang Yili and others points out that alkali sensitivity damage is the main reason of the reduction of output of Well 1 in oiliness tectonic Donghe, Tarim Basin. They believe in alkaline environment, clay particle is apt to disperse/migration so that the permeability reduces, and they put forward the notion of alkali sensitive damage reservoir [19].

Table 1 Common Potential Damages Caused by Clay Mineral to Hydrocarbon Reservoir

<table>
<tr><th colspan="2">Sensitivity</th><th>Sensitive Mineral</th><th>Damage</th></tr>
<tr><td colspan="2">Water Sensitivity</td><td>Montmorillonite, Degradation illite, Illite-smectite, Hydrous micas</td><td>Lattice expansion, scattered migration</td></tr>
<tr><td colspan="2">Velocity Sensitivity</td><td>Kaolinite, MIcrolite, Wool shape illite</td><td>Particles scattered migration</td></tr>
<tr><td rowspan="2">Acid Sensitivity</td><td>HCl</td><td>Chlorite, Pyrite, Hematite</td><td>Release particles, chemical precipitation
$Fe(OH)_3\downarrow$, SiO_2 gel</td></tr>
<tr><td>HF</td><td>Calcite, Dolomite, Anorthite, Zeolite</td><td>Chemical precipitation $CaF_2\downarrow$, SiO_2 gel</td></tr>
<tr><td colspan="2">Salt (Alkali) Sensitivity</td><td>Chemical compound contained calcium magnesium bivalent ion(high salinity liquid)</td><td>$Mg(OH)_2\downarrow$, $CaCO_3\downarrow$</td></tr>
</table>

In the process of drilling the external liquid (drilling fluid and filtrate) invaded into fractures, the secondary filling sensitive minerals (clay mineral and non-clay sensitive mineral) existed in fractures and the incompatible acid gas (CO_2, H_2S) will encounter a series of physical chemistry and to cause reservoir sensitivity damage (Table 1), organic matter, inorganic matter sediment, fracture-void blocking and the reduction of reservoir permeability.

C. Stress Sensitivity

Dual medium reservoir, under the cooperation of overburden pressure and fluid-power pressure, produces effective stress. The effective stress increases, compressed crack (even closed) and void increase oil gas seepage resistance, and the permeability of dual medium reservoir will decrease obviously[20～21]. Because of the existence of stress sensitivity, permeability of the core decreases to 50%-90% [22]. R search shows[23], when effective stress begin to increase, the crack firstly is reduced to close, which causes the dramatic reduction of rock permeability and stress sensitivity coefficient increases; along with the increase of effective stress (over 15MPa), the deformation of crack is already done. At this moment, rock porosity begin to deform, then the relevant permeability develops in a mild way, and at last the permeability remain unchanged because of the supporting function of particles. The deformation of crack is hardly to recover so that the rock permeability is hard to rise again when the rock is out of stress, which means that the crack hysteresis effect is obvious. Jiang Guancheng[23] believes that fractured carbonate reservoirs have stress sensitivity and hysteresis effect based on the regression analysis of permeability of fractured reservoirs and the relation between crack width and effective stress. According to their experiments, Jing Juexue and others draw a conclusion [25] that variation of stresses hardly affects permeability of rock core. The stress sensitivity of void core is less than fractured rock core's, and the stress sensitivity of natural fractured rock is less than artificial one's. Plus when permeability damage happened to artificial rock, the damage process is irreversible. Kang Yili[26] believes that the stress sensitivity of fracture-void carbonatite reservoirs is medium to strong and the stress sensitivity of void reservoir is weakest.

Besides, research shows that[27～33] under the action of stress, the pore structure of rock would be out of shape. And when the effective stress increases, the crack would be closed based on contraction; but when the effective stress reduces, crack would relatively inflate. During the drilling process of oil gas reservoir, the reservoir pore pressure gradually reduces and the effective stress born by the rock gradually increases so that the petrophysical parameter of oil gas reservoir goes worse and cause stress damage. In fact, the variation of stresses of fractured rocks is mainly reflected on the transformation of the crack. Once the crack is closed, it will affect the production of oil gas and even the discovery of it.

D. Water-lock Effect

Water-lock effect, also called as Aqueous trap, refers to the external liquid phase under the effects of drilling pressure differential enters deeply into fractures and voids to form meniscus in interface and to produce capillary resistance. Because of the capillary resistance and natural formation pressure, it is hard to flow back the outside invaded liquid, which causes the reducing of reservoir permeability, especially the damage for low permeability fractured water-lock oil reservoir[35～36]. Bennion and others[37～38] believe that Aqueous trap(water-lock) is caused by the water saturation of initial reservoir is far behind the bound water saturation. Research shows[39] that micro fractures(crack width<1μm) reservoir and fractures (crack width between 1～10μm) reservoir are difficult for solid particles and fibers to invade in. The main damage mechanism is that liquid phase invades to cause the increase of hydration shell and to form water lock. Water-lock damage mainly manifested in two ways: on the one side, it prevents the original wettability liquid in capillary or wettability liquid which under the positive pressure enters into capillary from flowing; on the other side, it contributes to the inhalation of wettability liquid and to hold it. Zhang Zhenhua and other scholars [40] believe that the Lunnna buried hill reservoir existed obvious water-lock effect after taken research on fractured carbonate reservoir of buried hill. The lower initial water saturation is, the lower absolute permeability of the core is, and more

serious the water-lock effect is. They also think that it is an effective way to reduce water-lock effect by adding surfactant.

II. PROTECTION TECHNOLOGY OF FRACTURE-VOID DUAL MEDIUM RESERVOIR

A. Selecting Appropriate Drilling Fluid System

Protecting technology of fracture-void reservoir drilling fluid system has different design plans in different regions, but the basic thoughts are[41]: ① compatibility; ② control of filtration; ③ pay attention to stress sensitivity; ④ avoidance of water-lock damage. At present, scholars and experts from home and abroad have worked out different kinds of drilling fluid systems preventing damages to reservoirs. Li Daofen[42] evaluates 11 kinds of drilling fluid used in Sichuan, the evaluation shows that calcium treated drilling fluids (which contains $CaCl_2$、CaO、$CaSO_4$) cause more serious damage to fracture-void carbonatite reservoirs and the filter cake has poor quality; polymer or sulphur drilling fluid causes damage to a lesser degree; drilling fluid with threadiness finishing agent cause the lightest damage. Gao Feng and others[43] introduces a drilling fluid applied to fractured oil reservoir, which means to add varying amounts of oil soluble temporary plugging agent YD-1 whose temporary plugging rate is 90%～93% and its solution plugging rate is 90%～97% in base fluid (5% bentonite plus 0.25% sodium carbonate). Jiang Guancheng[44] added different kinds and different sizes of temporary plugging agent at the same time, and he studied out a kind of drilling fluid which protects cracks located in a wider region. The recipe contains ① superfine $CaCO_3$(QCX-1), its particle size is between 5～20μm, the average size is 4μm; ② coarse grain $CaCO_3$,its partical size is between 5～20μm, the average size is 7μm; ③ oil soluble temporary plugging agent (FB-2), its partical size is between 2～100μm, the average size is 12μm. The evaluation on 9 kinds of recipe drilling fluid shows that their permeability recovery are rather high, average permeability gets to 86.5%. Sheng Li[45] used oil base drilling fluids with its recipe of +12.5%JMC+0.5%ABSN+3%$CaCO_3$ drilling fluid to effectively prevent strong water sensitivity and micro-fractured reservoirs damage. Wang Fuhua[46] and other scholars had a research about different reservoirs. They put different types of reservoir protecting agent into black MMH system to work out a broad spectrum plugging protecting drilling fluid which has an effective effect to fractured reservoirs. Zhao Zhongju[47] reports that American Acti Company developed a kind of microvesicle drilling fluid contained microvesicle which helps to decrease the density of drilling fluid, to produce bridge blinding in cracks and to prevent fractured reservoirs damage.

B. Employing Necessary Drilling Craft

1) Shielded Temporary Plugging Technology

Shielded temporary plugging technology[48～54] utilizes the two negative factors (differential pressure and solid phase particles in drilling fluid) produced in the process of drilling which cause damages to oil gas reservoirs to turn it into positive factors to protect oil gas reservoirs. When the reservoir is drilled open, utilize the positive pressure between bottom-hole pressure and reservoir pressure in hohlraum system of drilling fluid, within a very short span of time (10-20 minutes), force all types and sizes of artifical solid phase particles to enter into the narrow place of pore throat or fissure, and to form a shielded temporary plugging belt whose permeability is bordering on 0. It prevents the solid phase particles and filtrate further permeate and reduces the damage to reservoirs. Therefore, temporary plugging belt can be removed by perforation or acidification in the later construction. So it can keep the initial porosity state of the reservoir which enables to protect the diversion capacity of crack and void and to improve production of the well.

The key factor of Shielded temporary plugging technology is that there are enough bridging and filling particles which can match with the size of pore throat of reservoirs. As for fractured reservoirs, it needs relevant irregular particles. As far back as 1977, Abrmas put forward that add bridging material into mud to decrease the damage of stratum caused by solid phase particles [55]. He got the experiment result: when the size of bridging material is more than or equal to one third of the size of pore throat and its volume concentration is no less than 5%, the damage concentration is less than 1 inch. In early 20 century 90s, researchers made experimental study about bridge rules of bridge binding particles. According to a large number of bridge binding experiments[56-58], it shows: employing two third match

principle has the best effects, because 2/3 bridging particles can stabilize bridging on pore throat and fissure and the concentration of bridging particles should be no less than 3%. In recent years, Hands and other scholars point out that when temporary plugging agent particle D90 (90% of particles are less than the size) approximately equals to pore diameter, it can have a good temporary plugging effect [59]. D90 is measured on the distribution curve of temporary plugging accumulating particle sizes. Both 2/3 match principle and D90 are empirical rule. Cui Yingchun and others put forward to use shielded temporary plugging fractal theory which is to quantitively compute pore throat (or fissure) and fractal dimensions of temporary plugging particles, and to choose temporary plugging agent whose fractal dimensions are the same or close to pore throat and to use it as the optimization agent of this reservoir[60～61].

To successful carry out shielded temporary plugging technology should pay attention to the following points: (1) design a feasible well bore structure. To fully realize connectedness between cracks, it needs to make the boreholes as far as possible intersecting with cracks. Therefore it is often designed as directional well (high angle well) or horizontal well to enlarge oil drainage area and improve production of oil gas. (2) The drilling fluid system should match with the reservoir characteristics. Nowadays the special structured microfoam drilling fluid whose foam is not coalescence is cycle use. However, it can accumulate together in the borehole condition and form bridge blinding in fissure and porous to reduce the invasion of drilling fluid and to better protect dual medium reservoir. In Fusselman Oilfield of western Texas[62], microfoam drilling fluid is used to drill a horizontal well which successfully overcomes the loss of drilling fluid caused by fractured reservoirs; Chinese Shengli Oilfield have constructed 30 recycled microfoam wells to effectively protect oil gas reservoir. (3) Choose appropriate temporary plugging agent. Based on different characteristics of different oil gas reservoirs, choose different types of temporary plugging agent (acidsoluble, watersoluble, oilsoluble, and unidirectional temporary plugging agent). Research shows[63], spherical particles temporary plugging agent, threadiness temporary plugging agent and temporary plugging agent which do not adopt a steady shape are combined in different density, and to use them repeatedly in the process of drilling dual medium reservoir, then it is helpful to get the technology requirement of stable fissure. (4) Suitable removing blockage technique. Using shielded temporary plugging technology is a rapid way to quickly and effectively block the fissure of dual medium reservoirs. But the result of blockage leads to reduce the permeability of well wall area and greatly increase permeating resistance from oil gas reservoir to borehole. Therefore in the process of production, it is necessary to employ some techniques to remove temporary plugging filter cake and to improve oil production capacity. Jianghan Oilfield[64] has worked out a compound removing blockage technique of compound temporary plugging agent JHZD, and used SAA flushing fluid, AC flushing fluid and OX removing blockage fluid, according to well drilling, well completion and compound removing blockage technology. Based on well completing test, natural gas production get to 21×104m3/d (convert flow capacity to 45×104m3/d), is 10 times of offset wells of isostructure. It realizes the effective goal of single well.

2) Underbalanced Drilling Technology

Shielded temporary plugging technology is realized by the process of bridging-filling-blocking. To fulfill the temporary plugging effect, temporary plugging agent particles must form bridges in a short span of time under positive pressure. And for those which do not possess the heterogeneous reservoirs (e.g. large fractures, big relicts, karst caves and etc.), it is useless to employ shielded temporary plugging technology. Practices from both domestic and overseas show that employing underbalanced drilling technology and decreasing positive pressure is effective to deal with the leakage of large fractures and protect the kind of reservoirs [65]. Underbalanced drilling technology not only prevents reservoir damages and improves production of oil gas well, but also avoids complex situations happened underground, reduce contact time between drilling fluid and reservoir production and increase the rate of penetration (drilling rate up to 4 to 10 times).

In recent years, Tarim Liberation Well 128, Lungu Well 2, Lungu Well 4, over 100 million tons of oil (Banshen Well 7, Banshen Well 8) constructed in Qianmiqiao burried hill of Da

Gang Oilfield, Liugou marlite fractured gas reservoir of Yumen Oilfield, Sinkiang Xiaoguai Oilfield, Sichuan Petroleum Administration all employ underbalanced drilling technology to make breakthrough in exploration and development and to protect the reservoirs effectively. Underbalanced drilling technology used in horizontal wells and high angle wells traversing fractures can obviously increase percolation area of oil gas reservoir and production of oil gas well. The typical example is Canada Weyburn Oilfield (fracture-void reservoir) which combines underbalanced drilling technology and horizontal drilling technology. Compared with balanced deviated wells, initial production increased 10 times [66]. In China, most of carbonatite reservoirs in Tarim Lunnan burried hill have been developed in high angle fractured corrosion void or karst cave, which are dual medium system reservoir stratum with inhomogeneity between reservoir plane and vertical. During the construction process of Liberation Well 128, because of the growth of crack, on the one hand, employing horizontal drilling technology traversing crack to increase oil area; on the other hand, employing underbalanced drilling technology (mud cap drilling) and using the solid free polymer drilling fluid with certain amount of emulsifier in it for protection of reservoirs, to decrease water lock damage of reservoir as far as possible, to effectively solve the serious problems of the loss of drilling fluid during the process of drilling in this region, to get better effect to protect oil gas reservoir and to accumulate experiences for Chinese underbalanced drilling technology.

Although underbalanced drilling technology is relatively mature, it still has following shortages[67]: ① it is hard to choose suitable drilling fluid system for reservoir characteristics; ② it is difficult to protect interval and wall which are easy to collapse and leakage, especially in the process of coordinating with horizontal well, it is hard to guarantee real-time monitoring for the well path; ③ during the process of underbalanced drilling technology , it is hard to guarantee underbalance in the whole process because of the existence of surge pressure so that it cannot form effective filter cake on the edge of the dual medium crack. Once overbalance exists, outside solid phase and liquid easily enter into the reservoir crack and cause more serious reservoir damages. Besides, well-designed negative pressure is very important in explore dual medium reservoir by using underbalanced drilling technology. Over negative pressure may cause to the collapse of well wall, migration of particles, crack closure of well wall and damages of stress sensitivity.

III. CONCLUSION AND SUGGESTION

1) The reservoir mechanisms mainly included solid phase invasion, reservoir fluid sensitivity, stress sensitivity, water-lock effect and so on.

2) Selecting appropriate drilling fluid system and using necessary drilling craft including shielded temporary plugging technology (crack width < 100μm) and underbalanced drilling technology (crack width >100μm)) were the reservoir protection methods of dual medium reservoir.

3) Determination fracture effective flowing width accurately and selecting optimally temporary plugging agent matching up with the reservoir were the key of shielded temporary plugging technology. Selecting reasonable wellbore fluid and appropriate negative pressure was the core of underbalanced drilling technology.

4) Underbalanced drilling technology effectively solves the problems caused by shielded temporary plugging technology. It is pointed that superiority supplementary of underbalanced drilling technology and shielded temporary plugging technology is the development direction of fracture- void dual medium reservoir protection in the future.

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